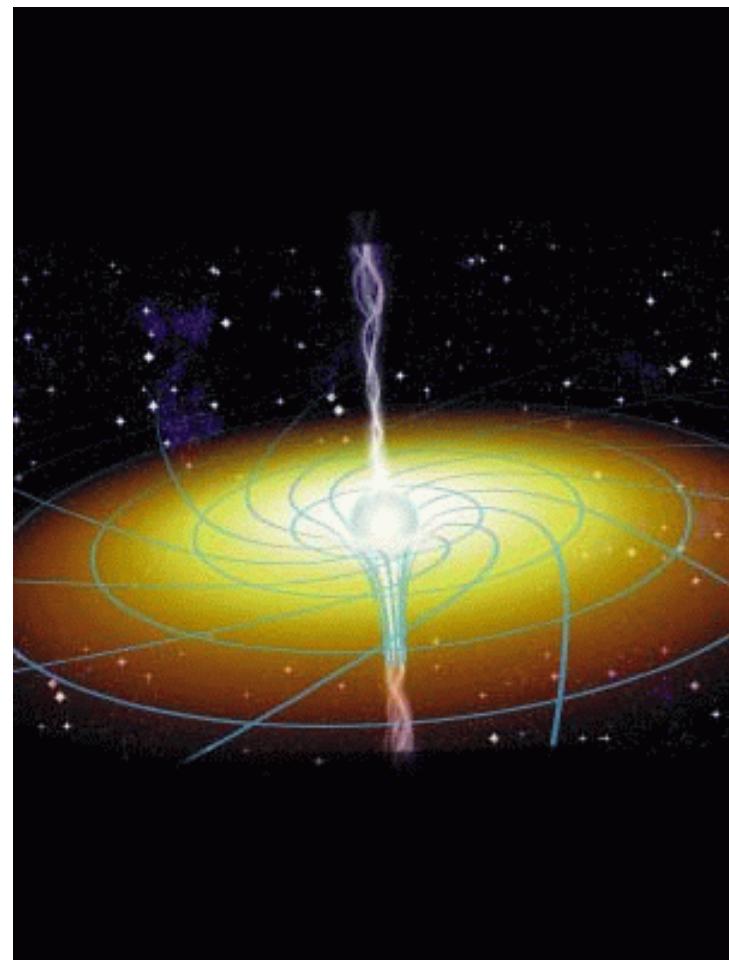


# New Science from the Spectra of Active Galaxies at the Highest Spectral Resolution

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## OVERVIEW

### Type I AGN

- \* Low-velocity photoionized outflows
- \* UV/X-ray column discrepancy
- \* Soft X-ray relativistic lines or dust? Variability studies required.
- \* Highly ionized Fe in absorption/ outflows
- \* Chandra & XMM status of observations of the Fe K lines
- \* Prospects of probing the accretion disk/ black hole with Fe K lines

# Soft X-ray (& UV) High-Resolution Spectroscopy of Type I AGN

- \* *Chandra HETG/LETG, XMM RGS, narrow absorption lines (<2000 km/s FWHM, best resolution ~300 km/s at 0.5 keV)*
- \* *Blue-shifted (~0–2000 km/s) → outflow*
- \* *Multiple ionization parameter, column density components (unstable part of S-curve, Krolik & Kriss 2001?)*
- \* *Many simultaneous UV (FUSE, STIS)/ X-ray (Chandra/XMM) campaigns now: UV columns consistently lower than X-ray.  
Controversy: Clumpy, multi-phase medium OR velocity-dependent covering factor (e.g. Arav et al 2003)?*
- \* *Relativistically broadened soft X-ray lines (O, N, C Ly $\alpha$ ) OR dusty warm absorber?  
Controversy: can theoretical models of the disk emission produce the required large EWs of the relativistic lines?*
- \* *Much higher velocity outflows seen in Fe XXV or Fe XXVI absorption:  
PG 1211+143 (~20,000 km/s), PG 0804+349 (~60,000 km/s), Pounds et al. 2003. Photosphere near black hole?*

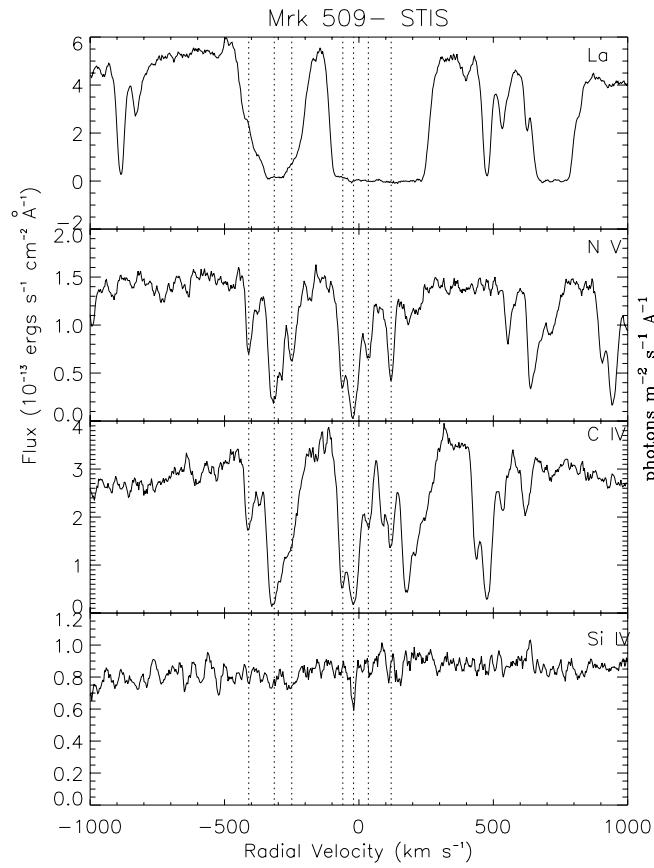
# Ionized Outflows in AGN, UV & X-ray Absorbers

*HETG & RGS observations reveal complex photoionized outflows (velocities  $\sim$ 0–1000 km/s); wide range of ionization states & multi-column components.*

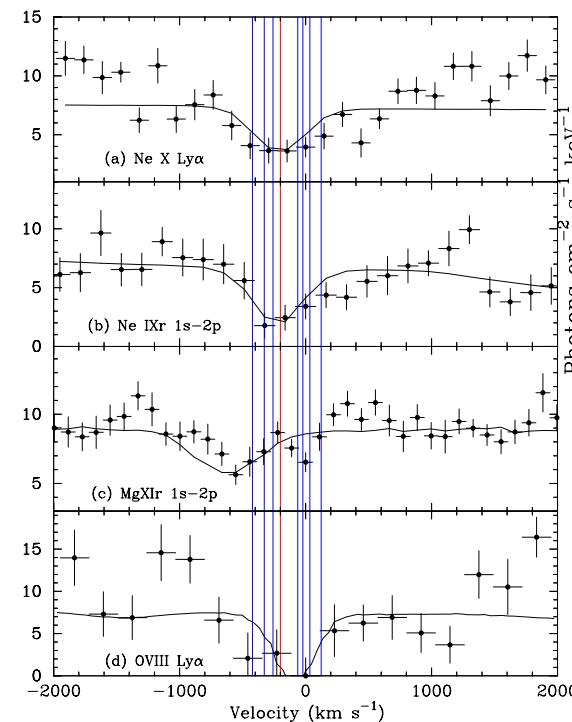
**Location still a key issue: VARIABILITY information desperately needed.**

Several simultaneous X-ray/UV campaigns reveal apparent discrepancies in inferred X-ray & UV absorbers can be reconciled with a clumpy, multiphase medium (X-ray/UV velocity space shared).

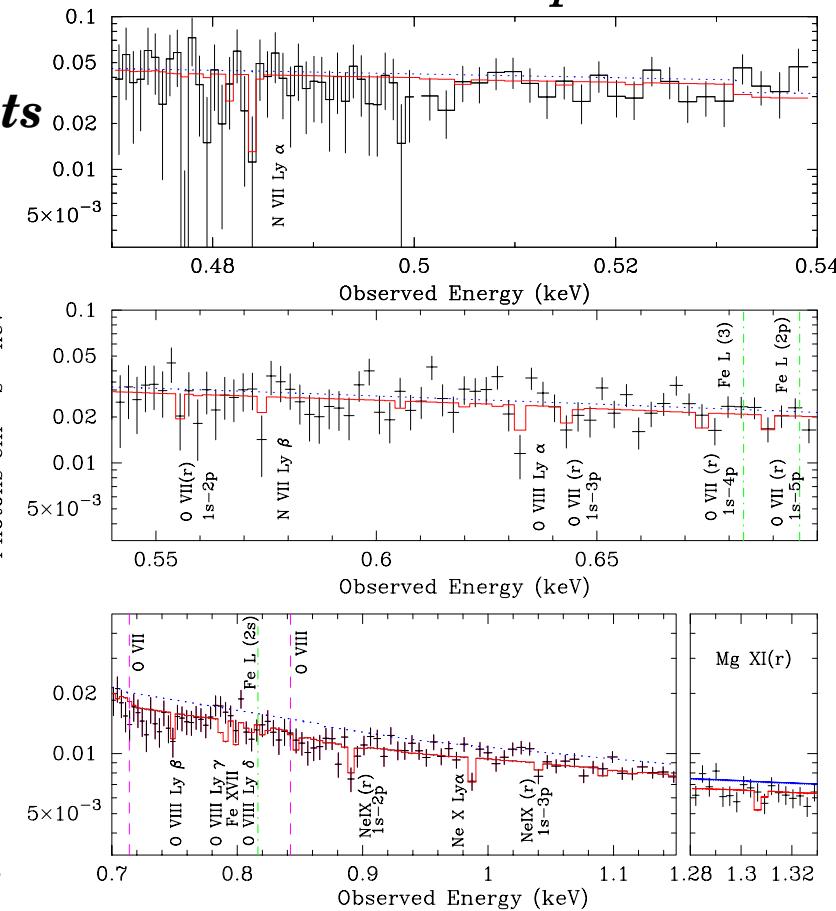
## Mkn 509 – STIS



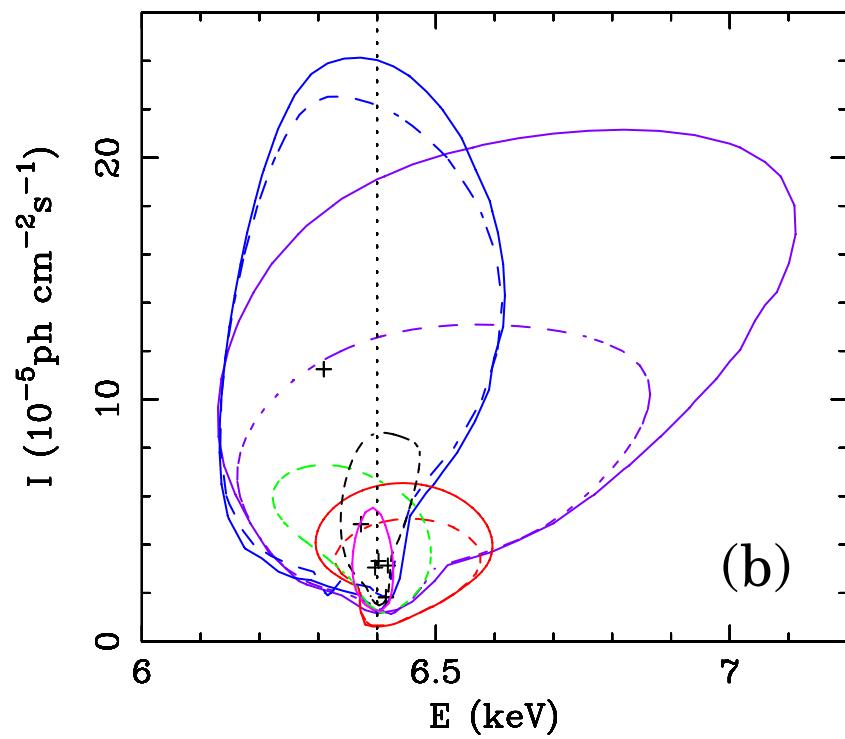
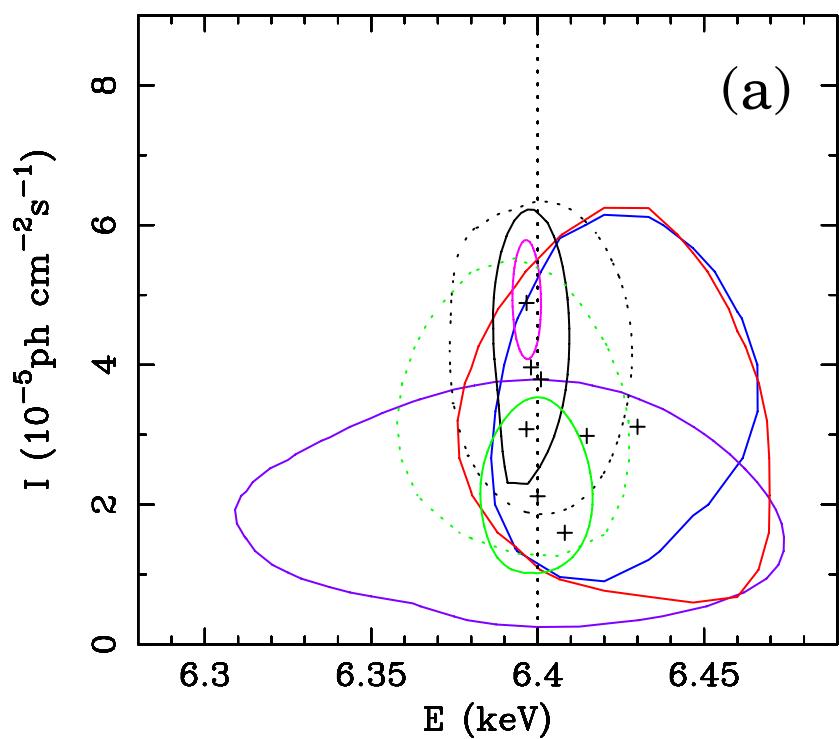
## HETG profiles, UV velocity components overlaid



## HETG spectrum

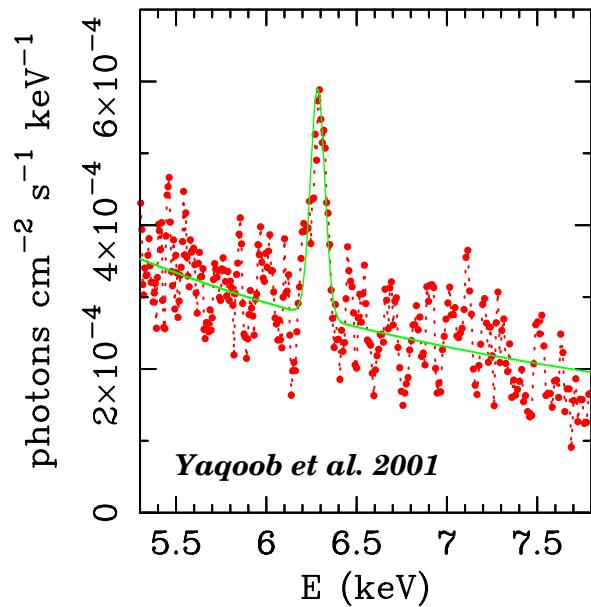


*Chandra HETG/HST STIS campaign on Mkn 509 (Yaqoob et al 2003)*



# NGC 5548 – Chandra Observes Narrow Fe–K Line

HEG Fe–K line at 6.4 keV  
FWHM  $\sim$ 4500 km/s, unresolved



*Narrow Fe K line could be from Torus, BLR, NLR  
Or is it from a disk emitting at large radii from BH?*

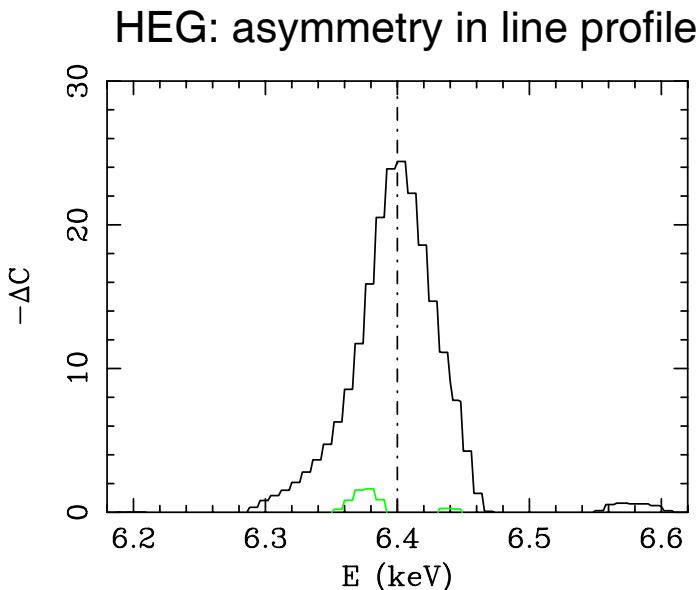
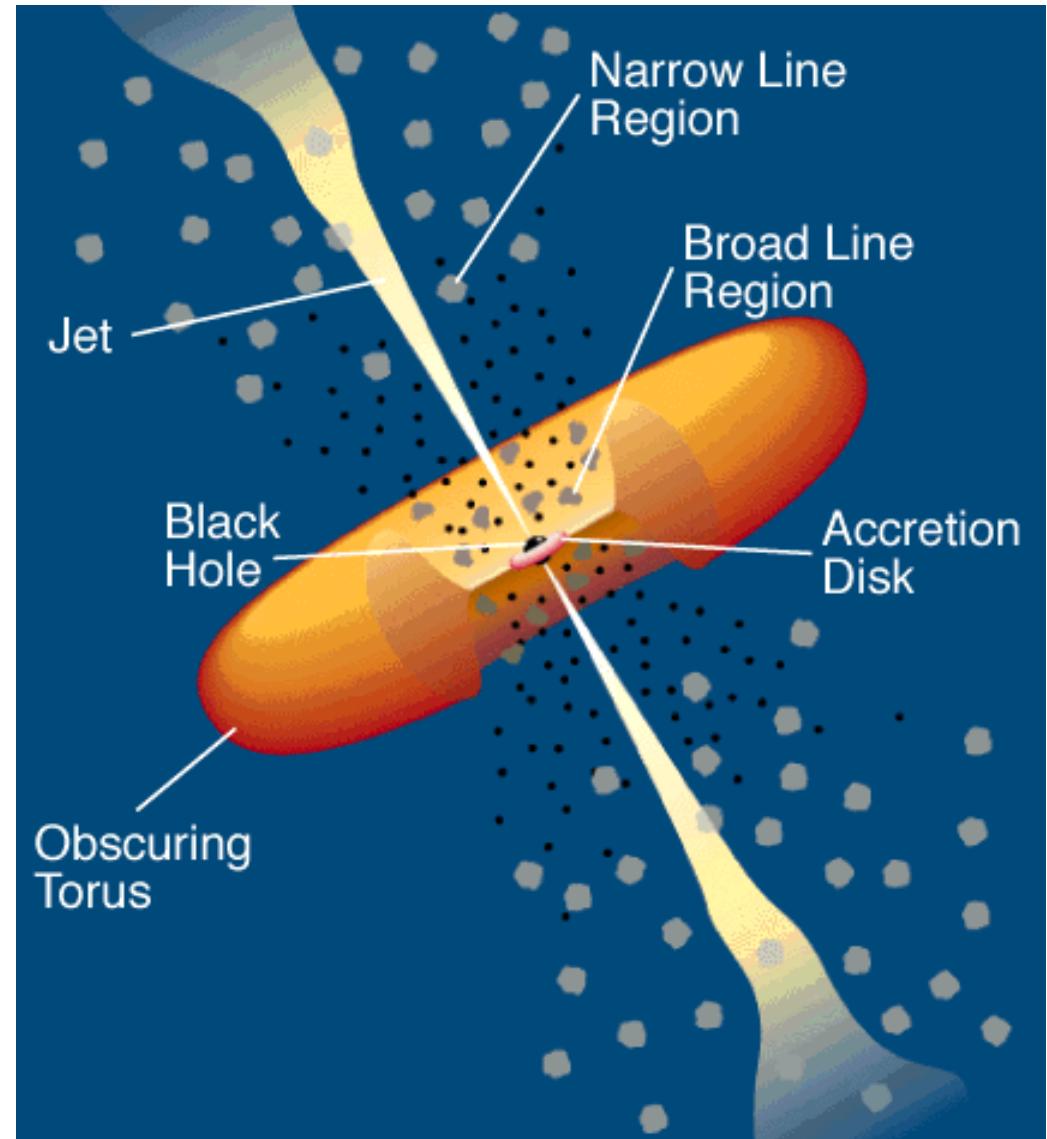
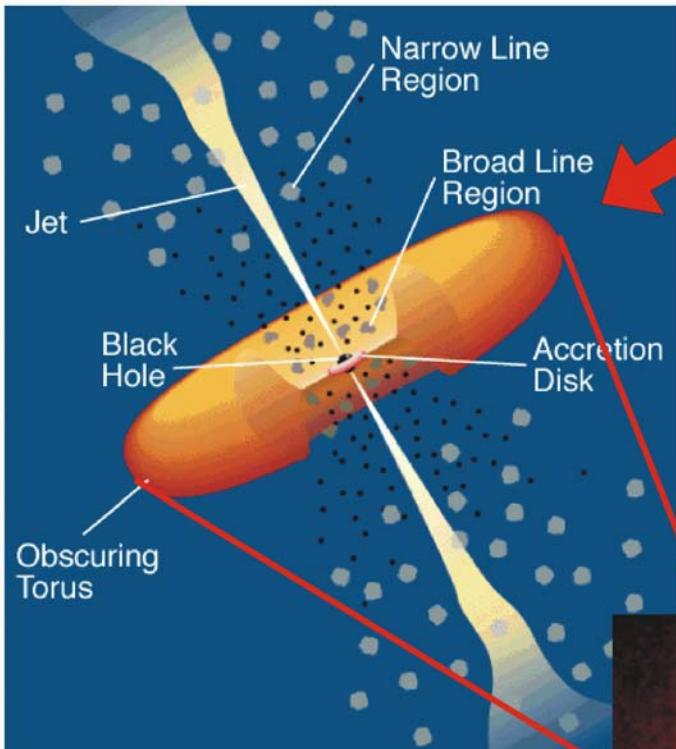


Figure: Urry & Padovani 1995

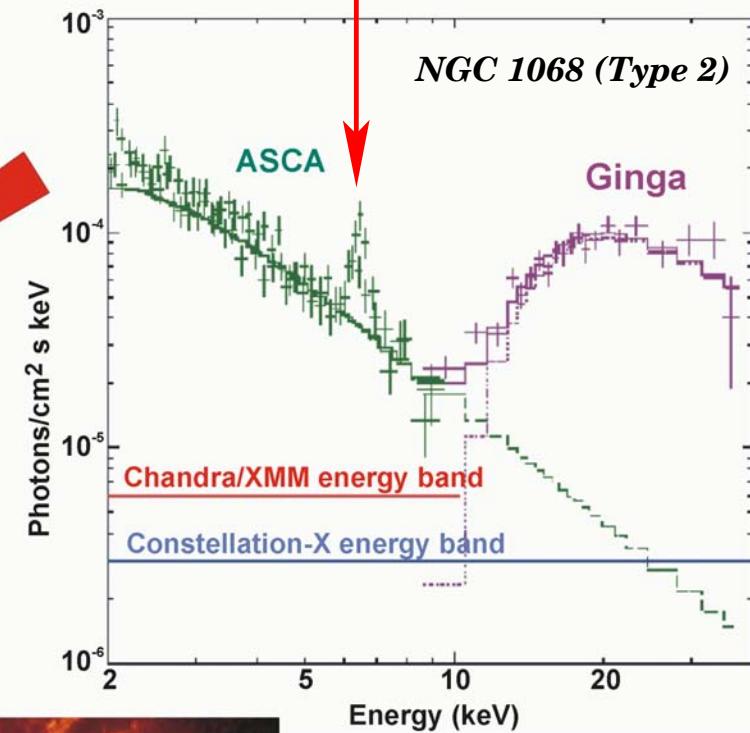
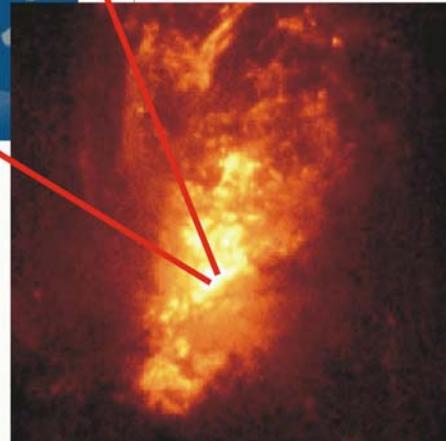
# Confusion of Disk & Distant-Matter Fe K Lines

Non-Disk Fe K line may be present in Type 1 AGN:  
CCD resolution cannot resolve disk component

AGN unification model: Disk might  
only be seen directly in Type 1 AGN



Urry & Padovani 1995



Done, Madejski, Smith 1996

Type 2 AGN:  
NGC 1068

# Relativistic Soft X-ray Lines

*Can XRS distinguish between disk lines & Fe-L edge?*

NGC 4593 –Chandra HEG

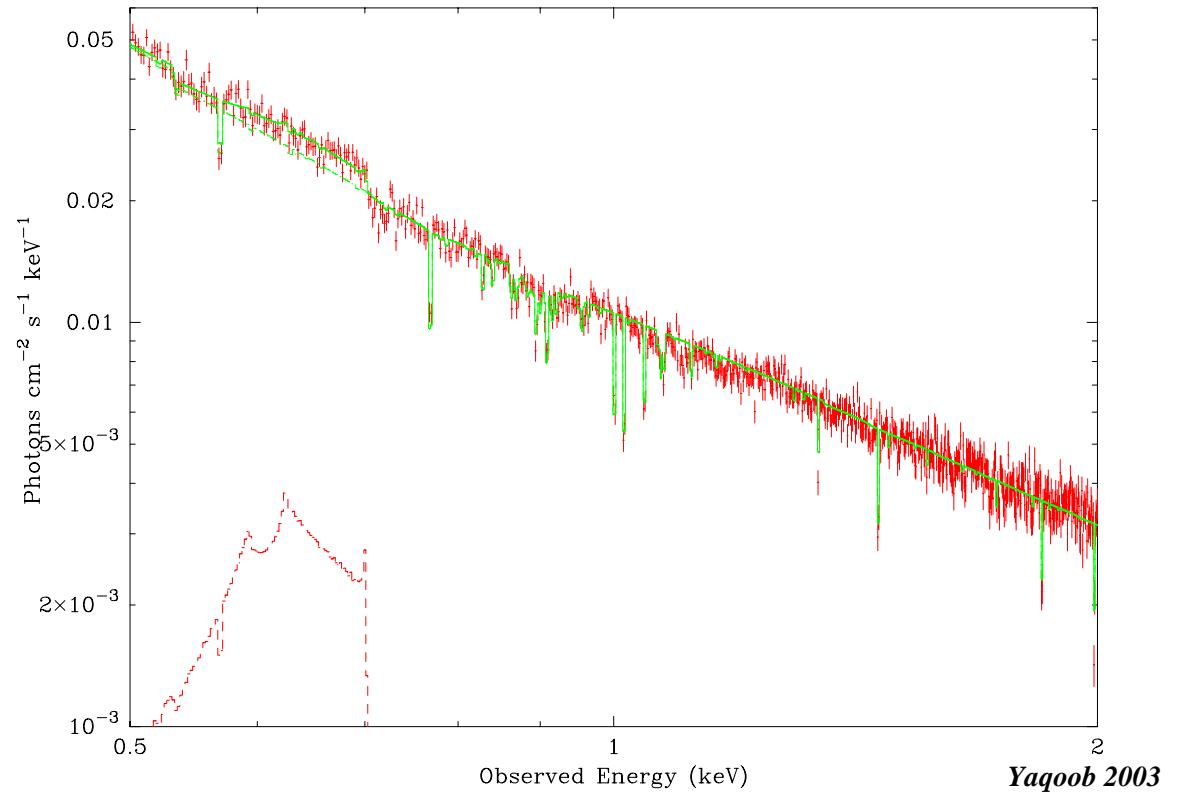
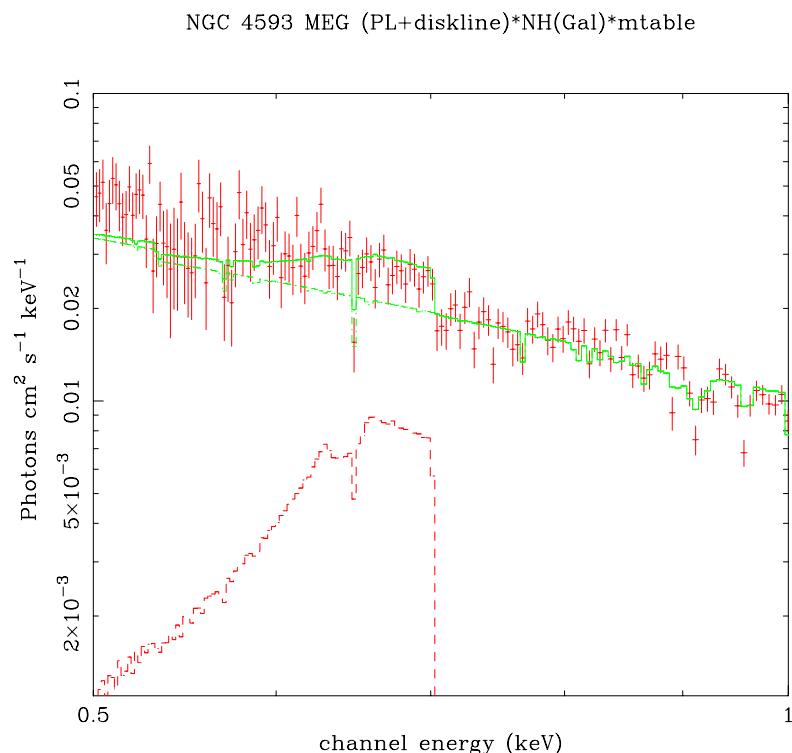
O VII line plus warm absorber fit.

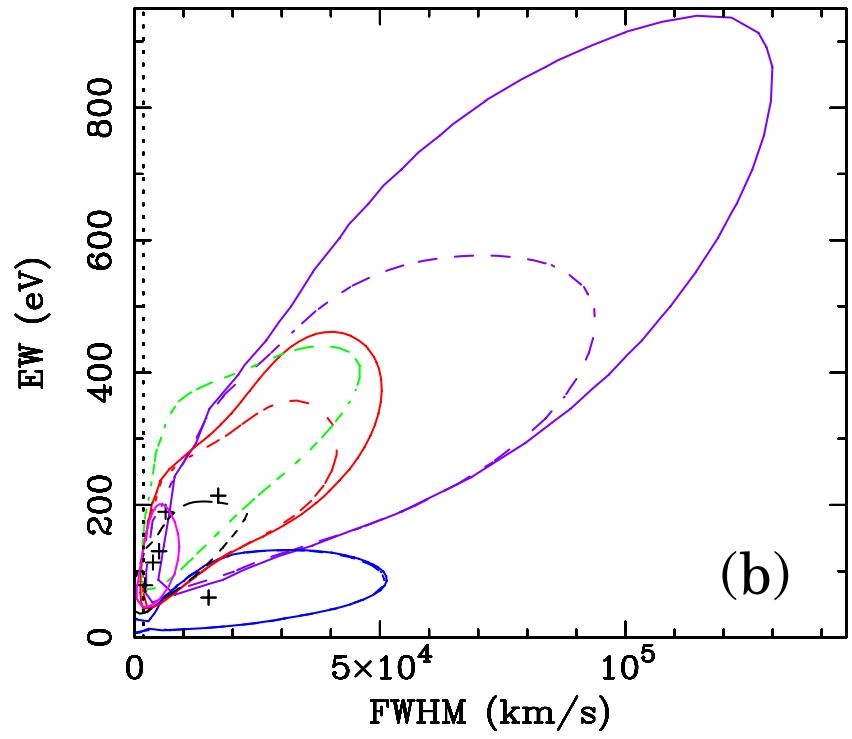
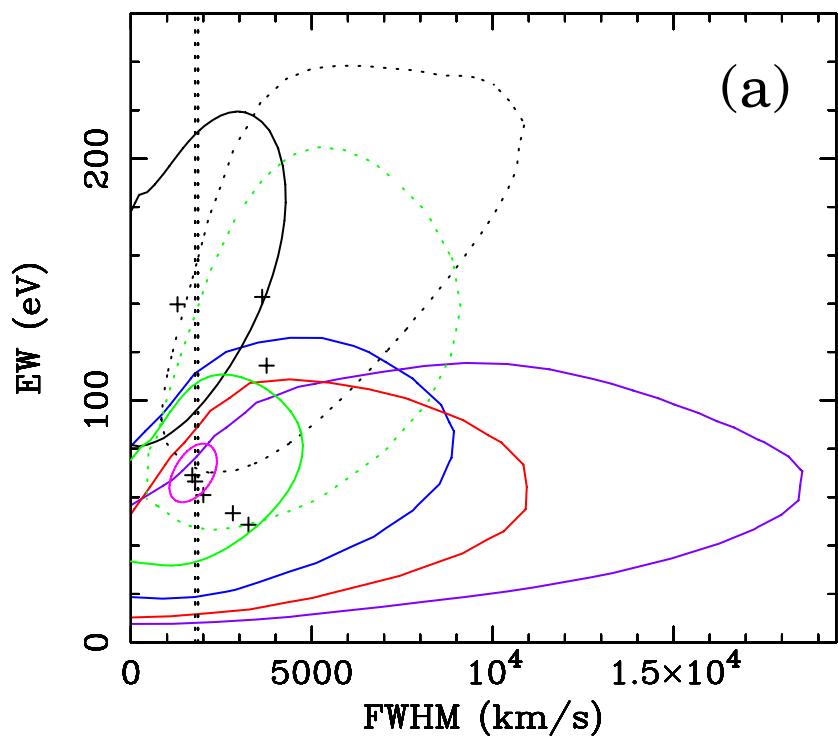
Disk inclination: 38.7 [−1.0,+0.9] deg.

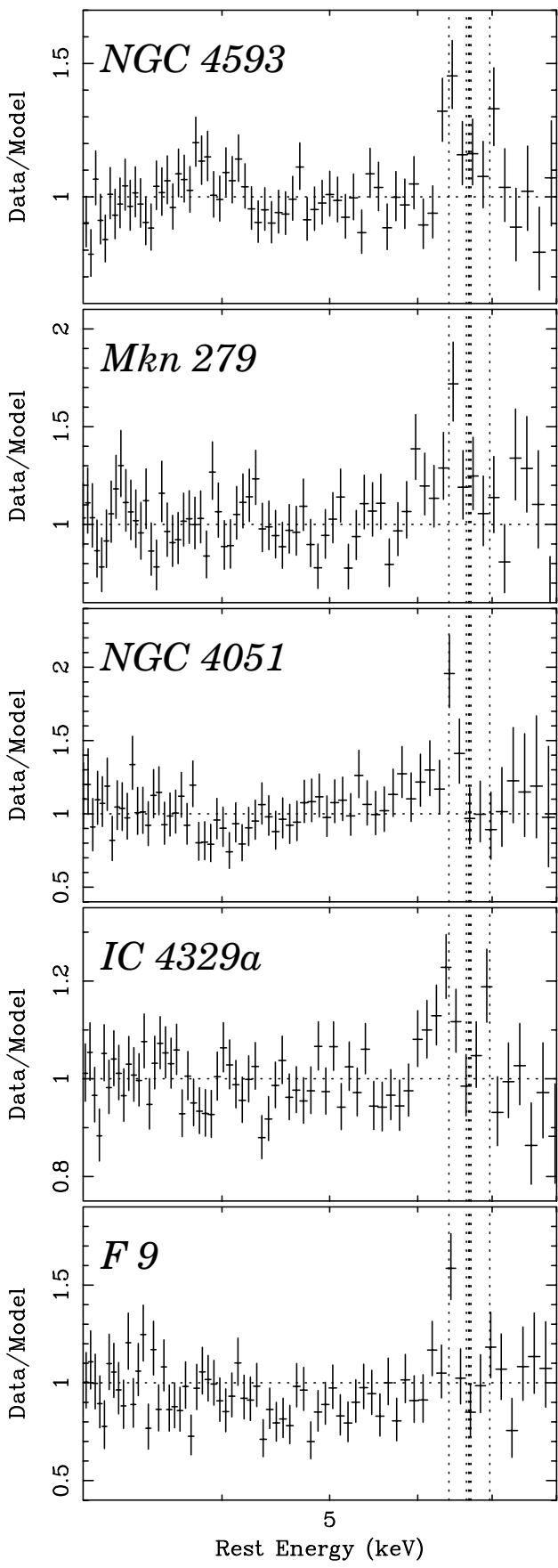
Edge model gives  $E_0=0.708$  keV.

Statistical errors on  $E_0$  only a few eV.

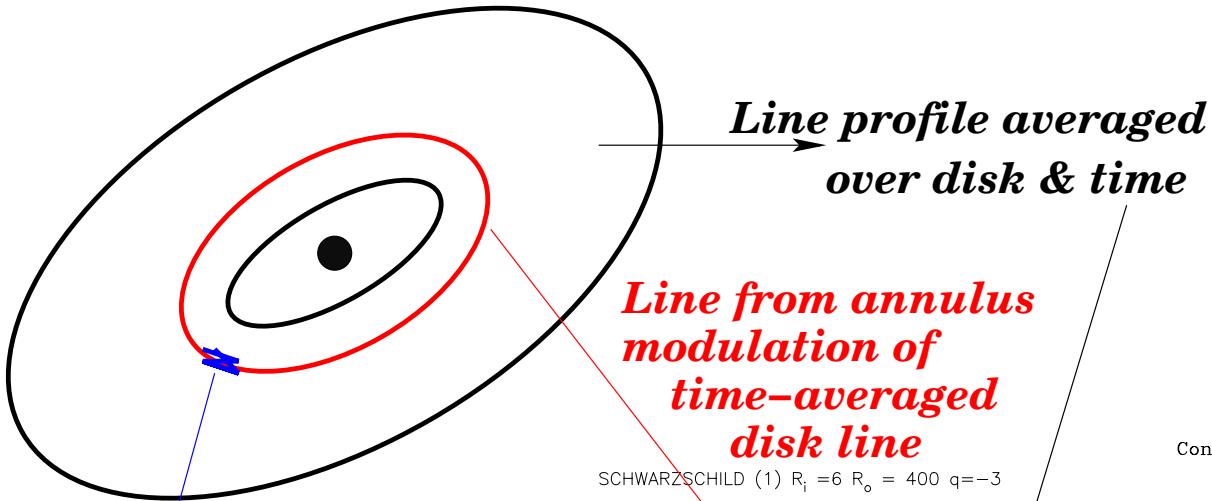
XRS simulation of NGC 4593. Warm absorber plus Fe–L model fitted by warms absorber plus disk line model. Exposure 100 ks.  $F(2-10) = 4\text{e}-11$  cgs.





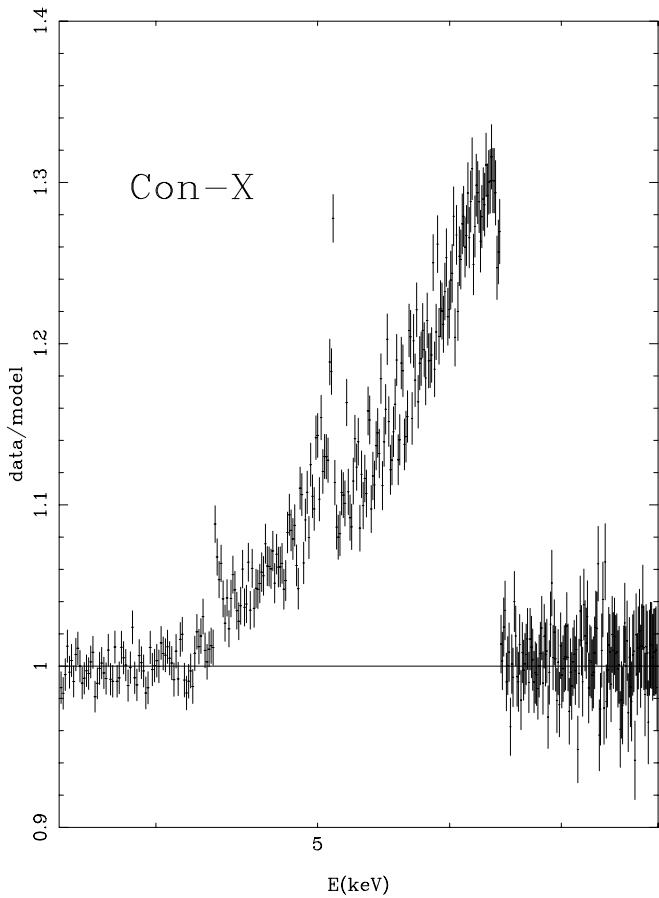
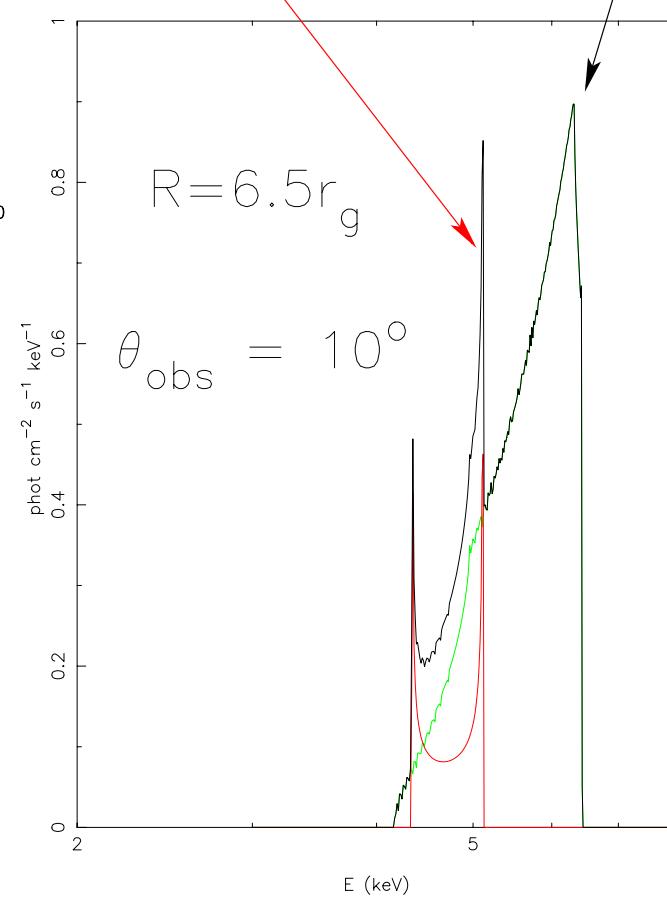
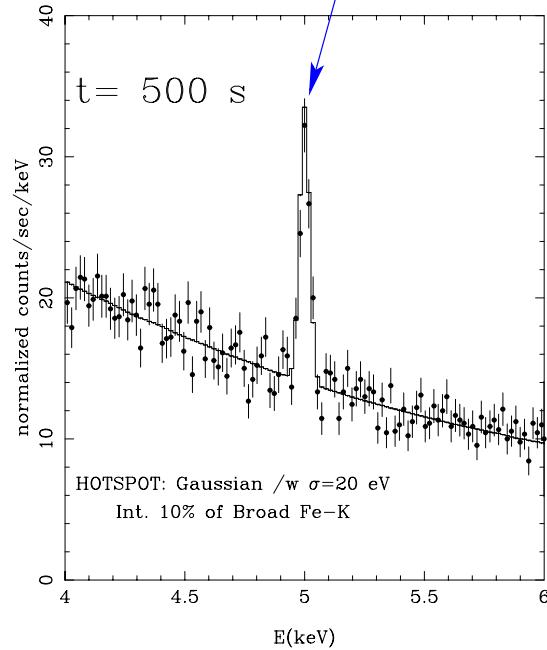


# Constellation-X Simulations



*At high time resolution:*  
measure hotspot  $\rightarrow$  BH mass

Constellation X simulation:  $po^*(laor + ga)$  rotating HOTSPOT  
Kerr line (EW=300 eV  $\theta=30^\circ$   $R_i=1.235$   $R_o=400$   $q=-3$ )  $F(2-10)=1.1e-10$



# How to Measure Black-Hole Spin

Extremities (peaks) due to hotspot,  $E_{\min}$  and  $E_{\max}$ , are a function of only:

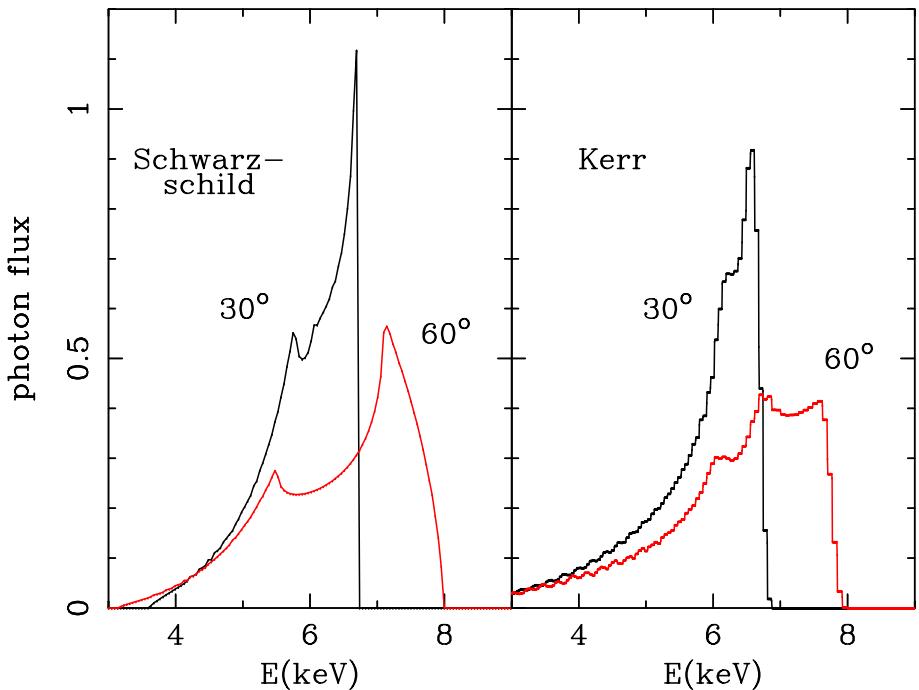
- radius,  $r$
- black-hole spin,  $a$
- disk inclination angle,  $\theta_{\text{obs}}$
- rest energy,  $E_0$ , of the Fe K $\alpha$  line (between 6.4–6.97 keV).

i.e.

$$E_{\min} = f(r, a, \theta, E_0)$$

$$E_{\max} = g(r, a, \theta, E_0)$$

Measure  $E_{\min}$ ,  $E_{\max}$ ,  $\theta_{\text{obs}}$  from time-averaged profile;  $E_0$  is 6.4–6.97 keV (or constrain from time-averaged profile); hence constrain  $r$  and  $a$ .



## Comparison of Relativistic Line Profiles: Can we measure spin?

Inner Radius: 6 Rg ( $a=0$ ), 1.24 Rg ( $a=0.9982$ )

Outer Radius: 400 Rg

Radial emissivity index,  $q=2.5 [R^{-q}]$

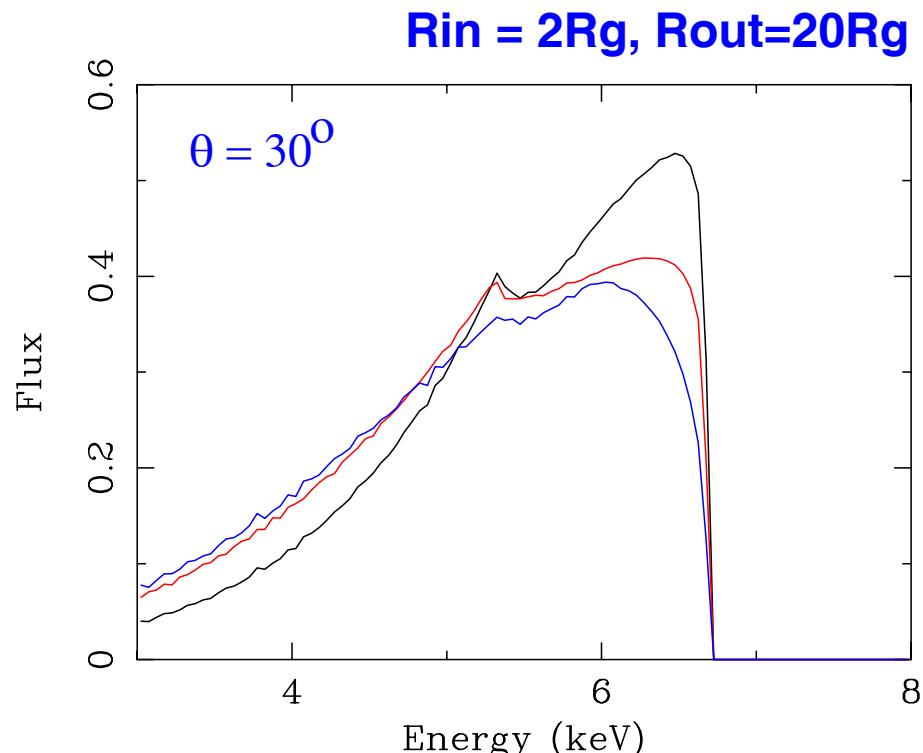
Can we distinguish between  
 $a=0$  &  $a \sim 1$ ?

Black:  $a=0$ ,  $q=3$

Red:  $a=0.9982$ ,  $q=3$

Blue:  $a=0$ ,  $q=4$

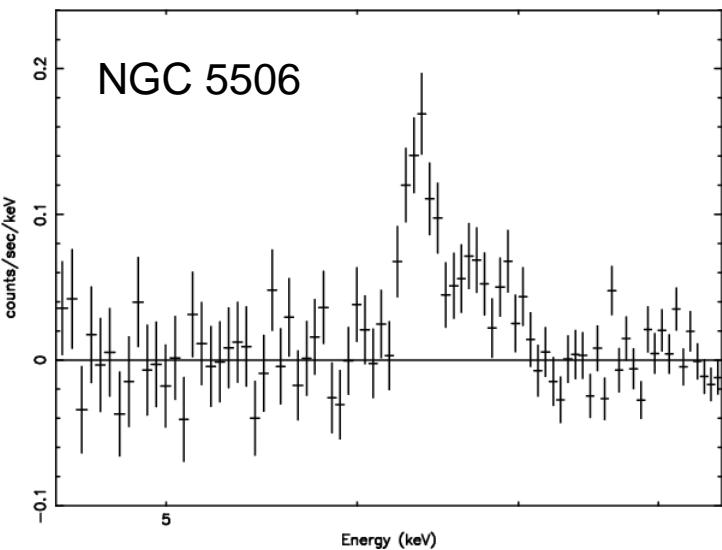
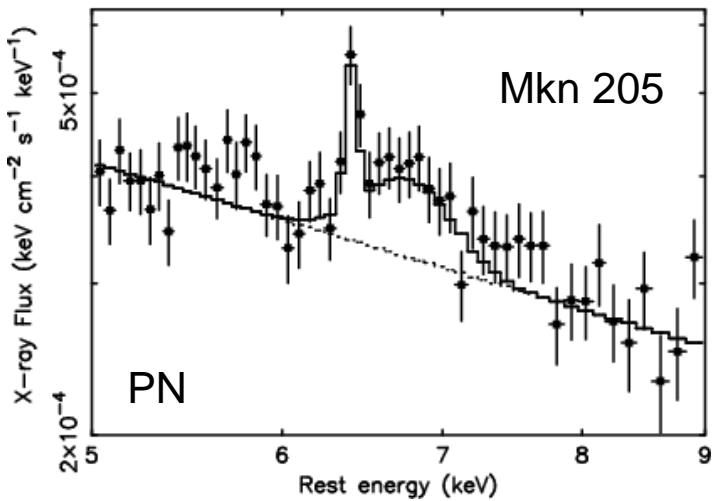
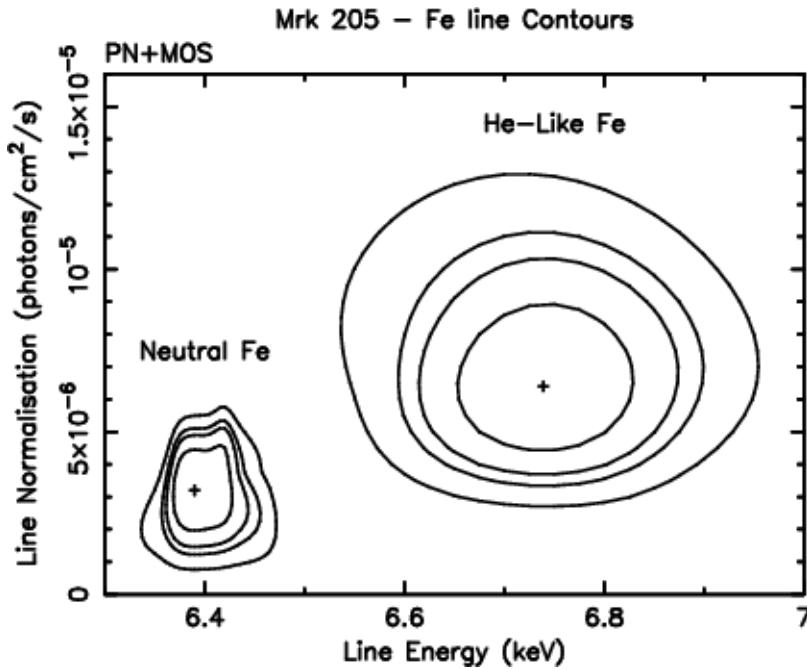
Profiles calculated using Dovciak, Karas, Yaqoob (2003) model



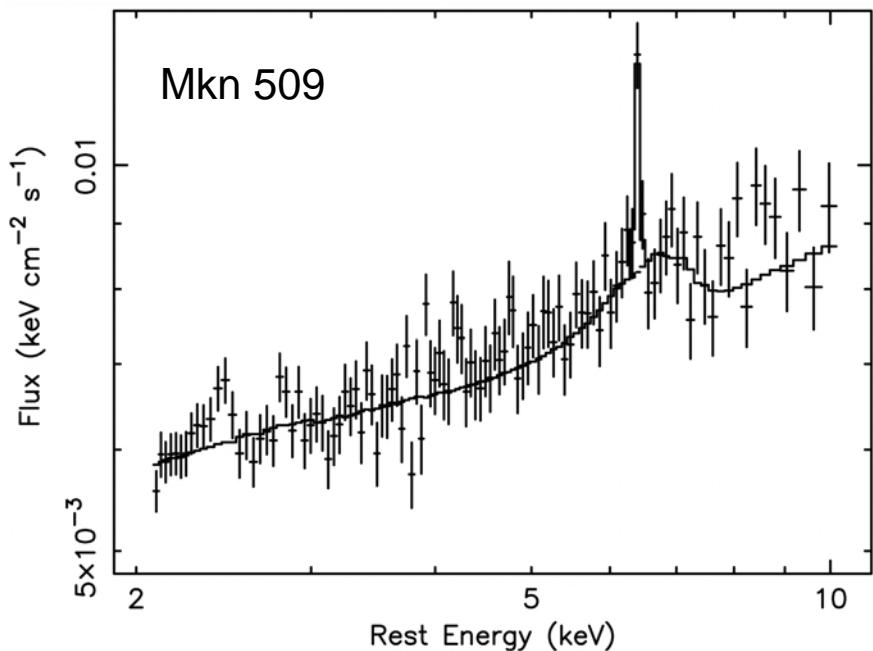
# He-like Fe Lines in XMM Data

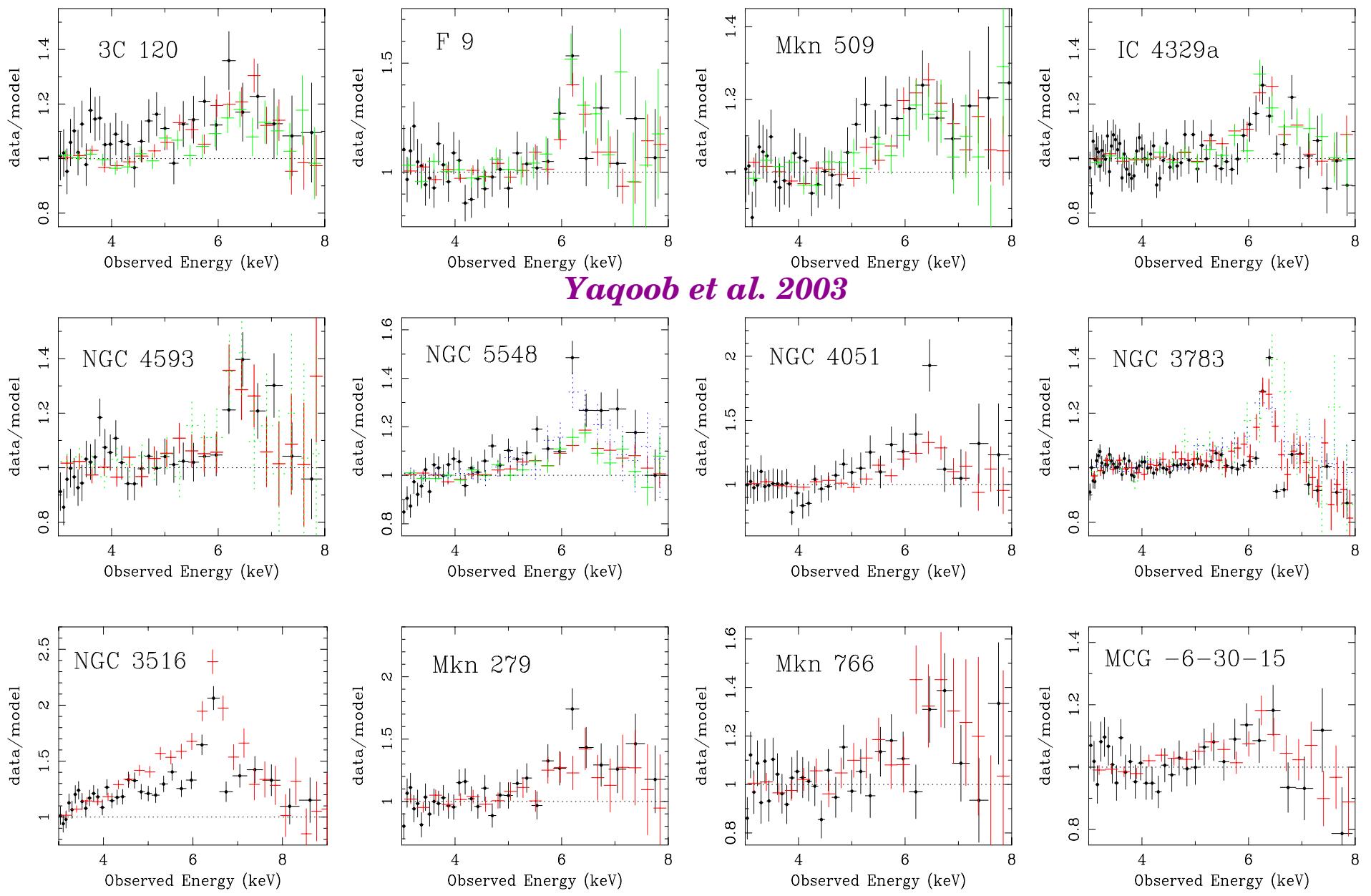
Matt et al. 2001

Mkn 205 Reeves et al. 2001



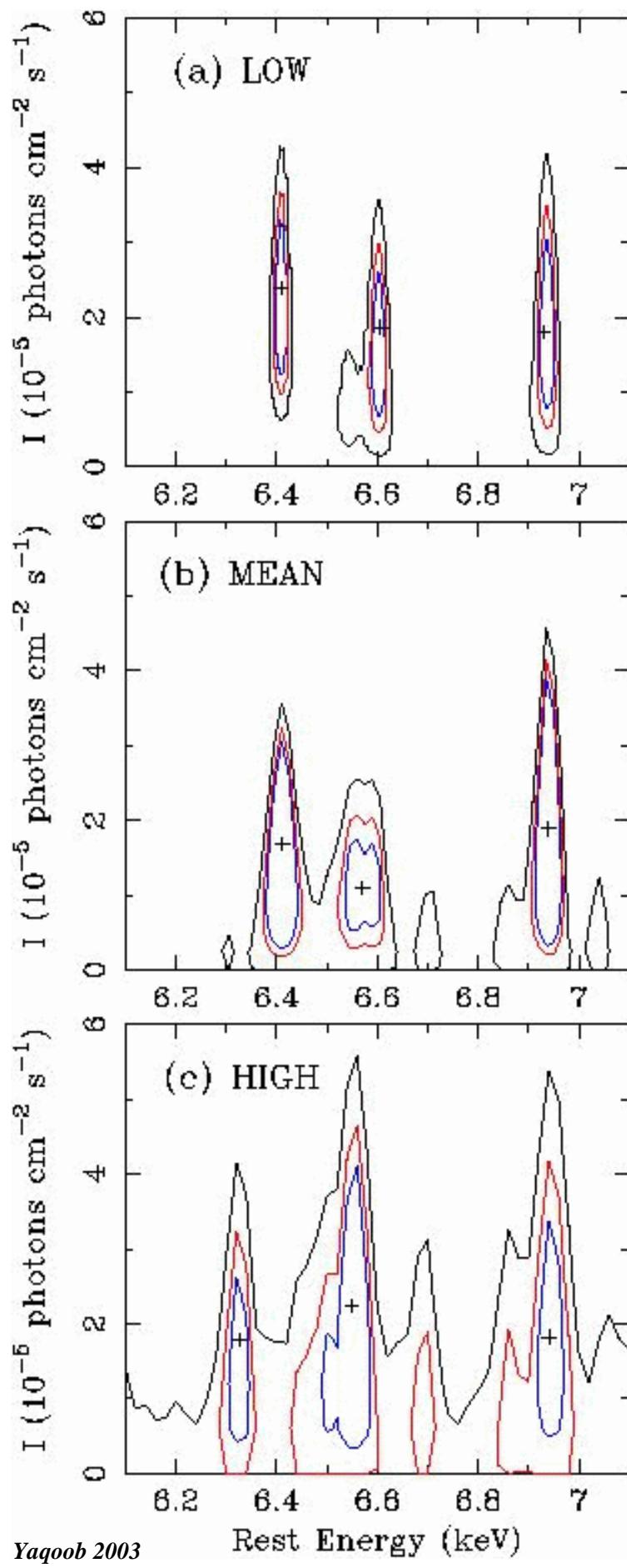
Pounds et al. 2000

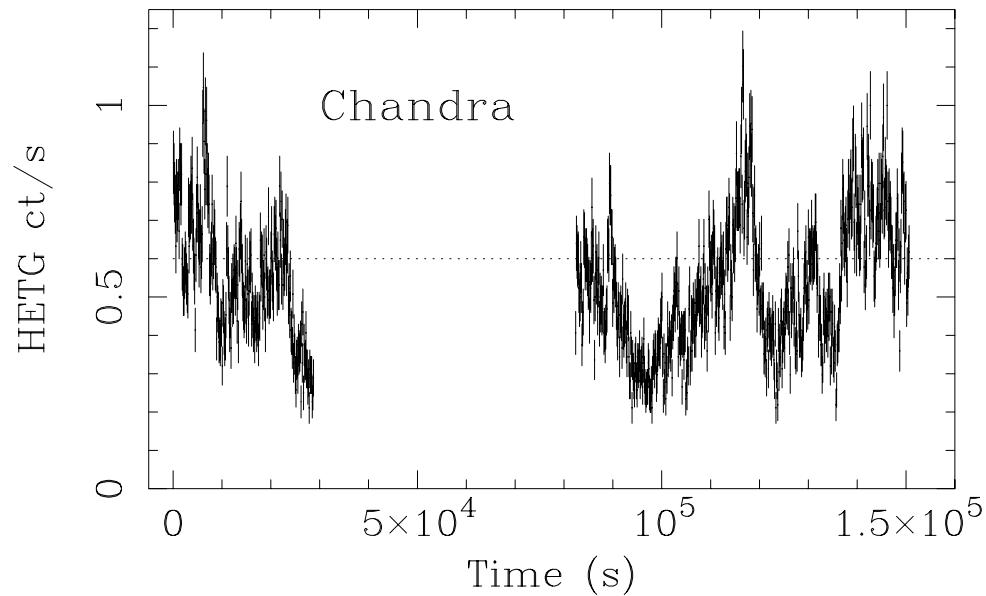




***Chandra HEG (BLACK) vs. ASCA S0+S1 (COLORED)***

# NGC 7314 – Rapid Variability of Fe – K Emission Complex





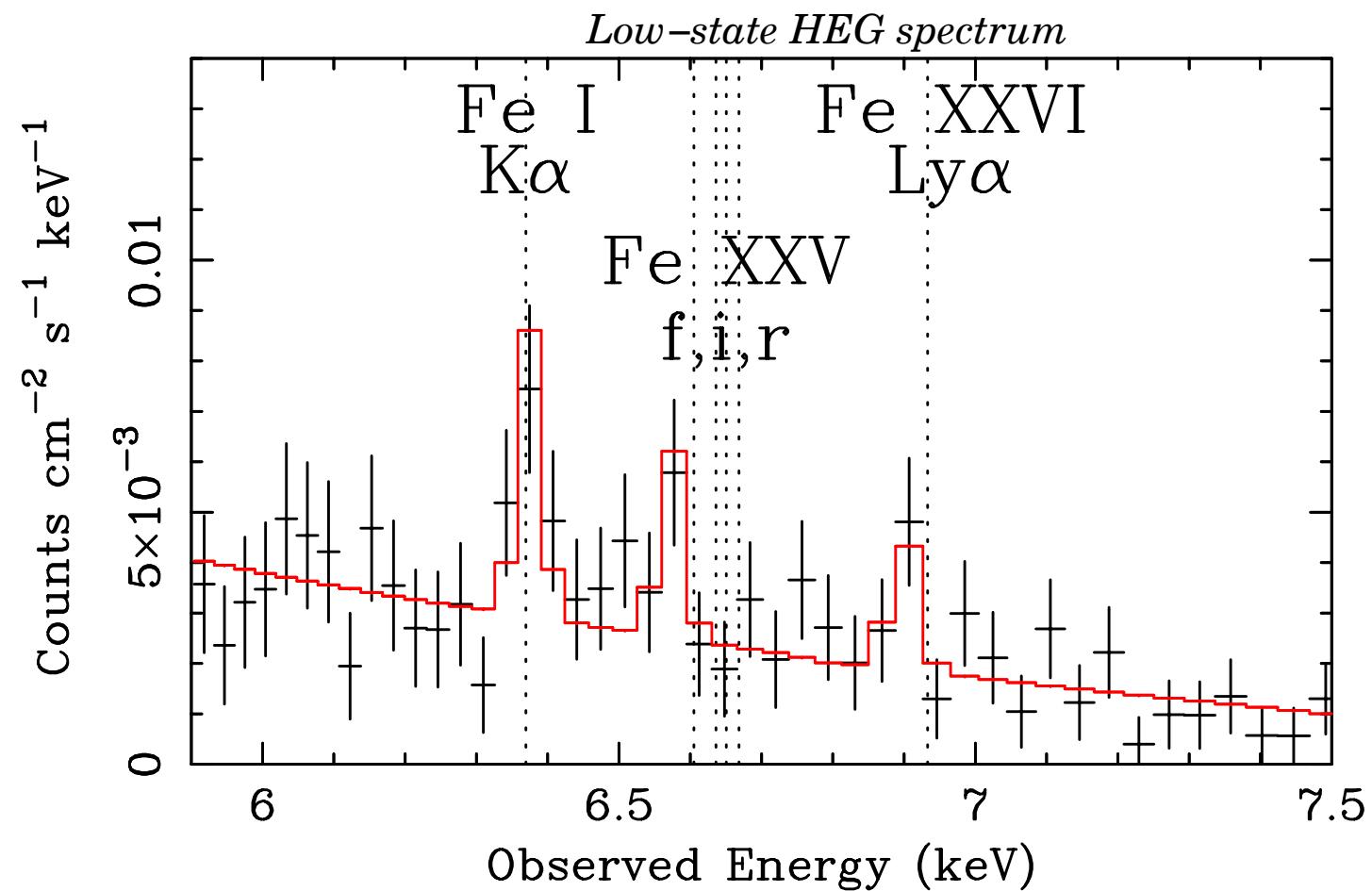
**NGC 7314: Fe XXV & Fe XXVI**  
**Narrow, rapidly variable, unresolved**  
**lines from an accretion disk.**

*He-like & H-like*  
*lines are redshifted,*  
*Fe I K line is not.*

*Redshift is  $\sim 1500 \text{ km/s}$ ,*  
*greater than systematic*  
*& statistical uncertainty.*

*Is He-like line f,i, or r?*  
*HEG cannot resolve.*

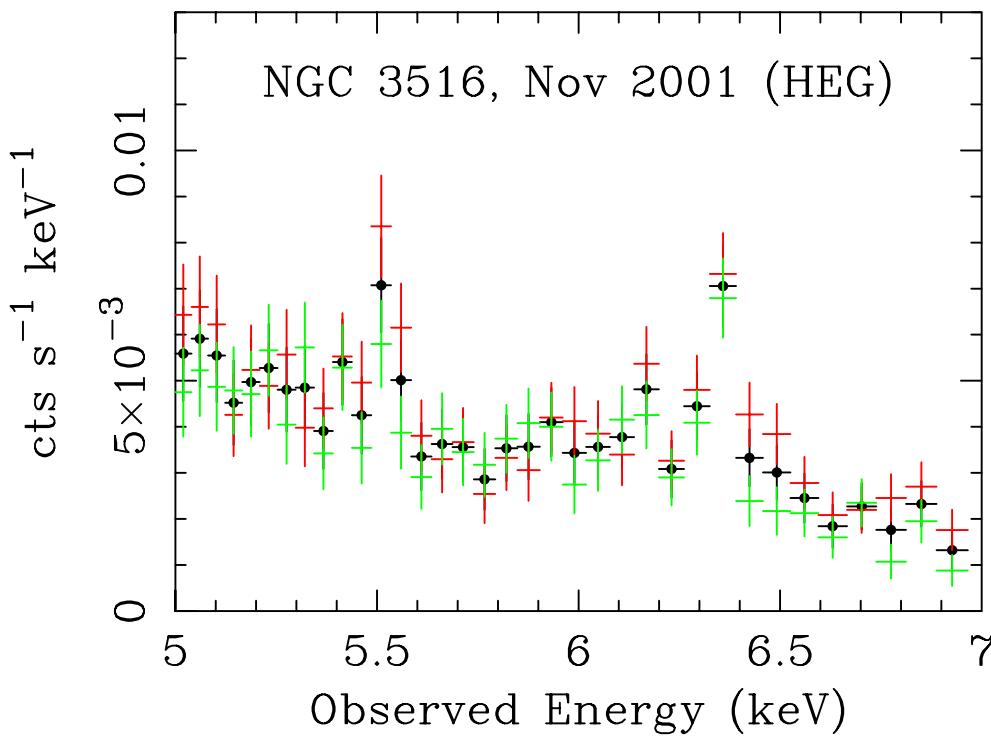
*Consistent redshift with*  
*H-like line if forbidden.*



# On The Reality of Narrow Fe-K Features from Localized or Non-axisymmetric Emission

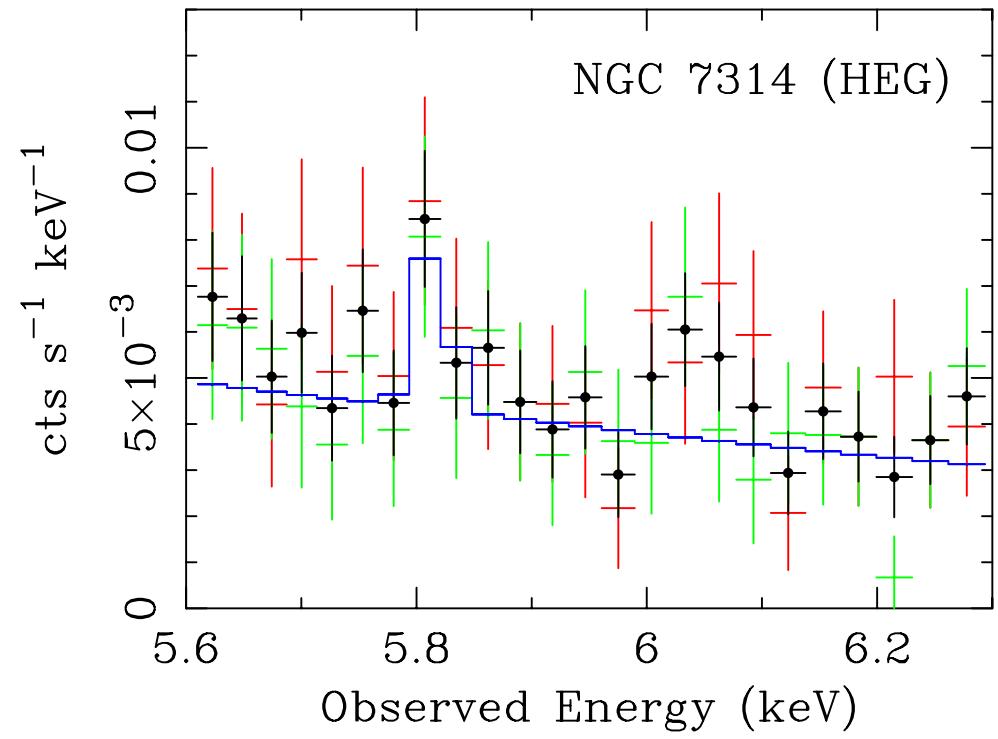
*NGC 3516, NGC 7314 Chandra Grating Data:  
Emission Lines detected in both + & - arms of the HEG*

RED: -1; GREEN: +1; BLK +1,-1



*See Turner et al. 2002*

RED: -1; GREEN: +1; BLK +1,-1



*Yaqoob et al 2003*

*Other examples: Mkn 766 (Turner et al. 2004); ESO 198-G24 (Guainazzi 2003)*